

Using Sea Turtle Carcasses to Assess the Conservation Potential of a Turtle Excluder Dredge

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Abstract.—Fisheries observers have documented interactions between sea turtles in the family Cheloniidae and the Atlantic sea scallop *Placopecten magellanicus* fishery. Sea turtle injuries resulting from interactions with scallop dredges are being mitigated through shifts in fishing effort and modifications to fishing gear. The standard New Bedford dredge can trap objects and crush them as they pass between the dredge frame and sea floor, so a modified turtle excluder dredge has been designed to reduce the likelihood of a turtle's passing under the frame when the dredge fishes on the seafloor. The key elements of the modified design are a forward cutting bar (which results in a sloping rather than a vertical face), a reduced number of bale support bars (just the center and outer bales), extension of the outer bale bars before tapering to the gooseneck (hauling point), and a reduction in the sources of entrapment between the depressor plate and the cutting bar via reduced spacing of struts. We evaluated the ability of the modified dredge to cause live sea turtles to pass over it by using loggerhead sea turtle *Caretta caretta* carcasses as a proxy. The carcasses were placed on the seafloor in the path of a towed dredge equipped with video cameras. Nine interactions between carcasses and the modified dredge were documented on video recordings. In each of the interactions, the carcass hit the dredge and passed over the dredge frame with little or no physical damage to the recovered carcasses. These carcass studies suggest that the turtle excluder dredge reduces sea turtle injuries associated with interactions between sea turtles and scallop dredges fishing on the seafloor.

The bycatch of sea turtles (family Cheloniidae) in commercial fisheries is an important conservation issue (Moore et al. 2009) and continues to garner the attention of the environmental community and others as many consider sea turtles a charismatic species. The commercial fishery for the Atlantic sea scallop *Placopecten magellanicus* is an important U.S. fishery, harvesting 26,545 metric tons of meats in 2007 with a value of US\$385 million (NMFS 2008). Ninety-five percent of the commercial sea scallop landings are harvested with a standard New Bedford dredge (NEFMC 2010) that consists of a steel bale, rectangular frame, sweep chain, and ring bag (Figure 1). Observers with NOAA–Fisheries have documented interactions between sea turtles and dredge gear used to fish

Atlantic sea scallops, with estimates of an annual loggerhead sea turtle *Caretta caretta* bycatch from 0 to 749 sea turtles per year (Murray 2004a, 2004b, 2005, 2007).

Sea turtle injuries resulting from interactions with scallop dredging are being mitigated through seasonal shifts in the fishing effort for Atlantic sea scallops and modifications to the fishing gear. An unknown number of unobserved interactions between sea turtles and dredges occur while the dredge is fishing for scallops on the sea floor or at the end of the haul when the dredge is pulled up through the water column. During deployment, dredges drop straight to the sea floor with the bag closed; thus, interactions with turtles are highly unlikely. It is not known what part of the haul catches sea turtles or when injuries occur, although most of the observed interactions that have resulted in turtle injuries occurred when the turtle was caught in the ring bag (DuPaul et al. 2004; Smolowitz et al. 2005; Haas et al. 2008).

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To prevent sea turtles from entering the ring bag during haulback, Atlantic sea scallop dredge vessels fishing south of 41°9.0'N latitude between May 1 and November 30 are required to use a chain mat (Federal Register/Vol. 71, No. 165/Friday, August 25, 2006). The chains in the chain mat are attached to the sweep and dredge frame (Figure 1), which essentially covers the opening of the ring bag with a grid of chains. The chain mat modification is expected to reduce serious injuries to sea turtles that result from their capture in the ring bag including drowning from forced submergence or being injured from heavy objects in the bag, slammed against the side of the vessel during haulback, dropped on deck, or crushed by the dredge (NMFS 2009).

Although the chain mat is expected to greatly reduce injuries that result from water column interactions between sea turtles and dredges, the chain mat is not expected to mitigate sea turtle injuries that could occur as a result of benthic interactions between sea turtles and the forward parts of the dredge frame. When a sea turtle contacts a New Bedford standard dredge that is fishing on the seafloor, we expect the turtle to either get stuck in the forward portion of the dredge frame, go up and over the dredge frame, or pass underneath the dredge frame. Sea turtle injuries associated with benthic interactions could occur upon contact with the dredge frame or if the turtle passes under the cutting bar (between the dredge and the seafloor).

In this study, we evaluated the conservation potential of an Atlantic sea scallop dredge that would exclude turtles and that was designed to reduce sea turtle injuries that could result from benthic interactions. We summarize previous work and present new data to assess the likelihood of reducing the two most likely sources of benthic injury: contact with the dredge and passing under the cutting bar. Rather than use live sea turtles to evaluate the conservation potential of the turtle excluder dredge, we used the carcasses of loggerhead sea turtles as models.

Development of Turtle Excluder Dredge

The standard New Bedford Atlantic sea scallop dredge and two prototypes of the turtle excluder dredge were evaluated in Panama City, Florida (Milliken et al. 2007). Divers placed hard-shell loggerhead carcasses in the path of a dredge being towed by a research vessel. Benthic interactions between the carcasses and the dredges were recorded through dredge-mounted and diver-held video cameras. After each interaction with the dredge, the carcasses were recovered and their damage was assessed.

In 2005, divers deployed three hard-shell sea turtle carcasses in front of the standard New Bedford dredge.

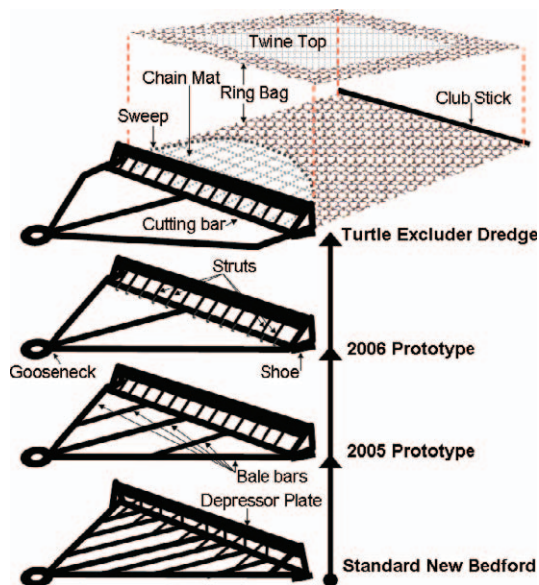


FIGURE 1.—Progression from the standard New Bedford dredge to the Cfarm turtle excluder dredge. All dredges pictured consist of a heavy steel bale welded to a rectangular frame. The bottom of the frame consists of a rectangular steel “cutting bar” that rests on steel shoes. Attached to the top of the frame is a forward-angled depressor plate. At the bottom of the frame, fastened to the shoes, is the sweep chain. The lower portion of the collecting net (called the ring bag) is attached to the sweep chain. The chain bag is fabricated out of welded steel rings and links. The top of the collecting bag consists of a twine top. A club stick is attached to the aft end of the net that holds the bag’s shape and facilitates dumping. Most vessels use dredges between 4 and 5 m wide.

All three carcasses went under the bale, got stuck against the cutting bar, were dragged along the bottom, eventually went under the cutting bar (between the cutting bar and the sea floor), and got damaged (abraded, chipped, and cracked) in the process. Even with this minimal testing, it was apparent that objects can get trapped under the bale bars or under the depressor plate. Because resources were limited and we wanted to reach conservation goals as quickly as possible, we began to modify the potential problem areas rather than invest more resources in further testing a suboptimal dredge.

The modified dredge was designed to reduce the likelihood of a sea turtle passing under the frame when it is fished along the sea floor. The new frame design is a significant departure from the New Bedford scallop dredge design because the cutting bar is moved forward of the depressor plate so that a sea turtle encounters a sloping (approximately 45°) rather than a vertical (approximately 90°) structure (Figure 1). The new

TABLE 1.—Serious injury guidance for sea turtles captured in scallop dredge gear. Category 1 = low chance of survival; category 2 = medium (50%) chance of survival; category 3 = high chance of survival. If a sea turtle is found with multiple injuries in different categories, the animal is placed in the category of the most severe of the injuries. Based on Table 1 of NMFS (2004).

Category	Description
1	Crack through the scutes on any area of the carapace other than marginal scutes Crack through plastron Any crack (either through or not through the scutes) over the vertebral column Any crack (either through or not through the scutes) over the anterior to mid carapace Bleeding from the rectum, nose, or other orifice Injuries to head with impacts to the eyes, nares, or oral cavity Injuries to the neck affecting the spinal cord, dorsal musculature, dorsal cervical sinus, or trachea Abnormal behavior abnormal (e.g., not able to right itself or not moving in water) Comatose, revived, and released with injuries other than those listed in category 3
2	Comatose and successfully revived on deck and released Carapace cracks that do not go through the scutes (on any area of the carapace besides the vertebral column or the anterior to mid carapace) or through the plastron Injuries to flippers that may impair movement or function
3	Carapace cracks on marginal scutes Minor or superficial injuries to neck Superficial cuts to flippers that do not impair movement or function in animals with good body condition No apparent injuries

design utilizes a wide depressor plate (20 cm), and the struts are closely spaced (30-cm spacing) and extend between the depressor plate and the forward positioned cutting bar. In order to allow a sea turtle to escape upwards over the dredge, all modified dredges had fewer than the typical seven bale support bars, but the number of bars varied between prototypes.

Prototypes of the turtle excluder dredge were evaluated in 2005 and 2006. Both prototypes had bale support bars removed. The 2005 dredge had two inner bale bars as well as the outer and center bars, while the 2006 dredge had all the inner bale bars removed except for the center bar (Milliken et al. 2007). Additionally, the cutting bar was angled and curved steel “turtle guards” were added forward of the cutting bar in 2006 (Figure 1). During some preliminary testing in 2005, divers deployed one loggerhead carcass and one fiberglass turtle model in front of the prototype dredge. The carcass got stuck against the cutting bar and was effectively held there by a bale support bar until it passed under the cutting bar. The fiberglass model hit the cutting bar in a location where there was no bale support bar and flipped over the dredge. Divers deployed five carcasses in front of the 2006 prototype during 12 separate trials to assess perceived problems areas of the dredge; thus, the placement of the carcasses was not random. Eight carcasses went over the prototype, two carcasses were caught at the corner between the bale and the cutting bar, one carcass was caught under the bale, and one carcass was held against the face of the prototype with its front flippers under the cutting bar. Approximately 13 kg of weights were attached to this last carcass in order to make it negatively buoyant, and the weights may have hung on

the face of the dredge preventing the carcass from sliding completely over the prototype.

Two important trends emerged from the carcass studies using the standard New Bedford dredge and the 2005 and 2006 prototype dredges. First, substantial carcass damage occurred when the carcasses passed underneath the cutting bar, and little or no carcass damage occurred if the carcass passed over the dredge frame. According to National Marine Fisheries Service (NMFS) working guidance on serious injury evaluations (Table 1), all carcasses that went under the cutting bar would be placed in category 1 or 2 (low to medium survival), and those that did not go under the cutting bar would be placed in category 3 (high survival). Carcasses that passed under the cutting bar had patterns of damage consistent with what has been documented from observers on commercial scallop vessels (Haas et al. 2006). The second important trend is the decrease in the proportion of carcasses going under the cutting bar. Carcasses went under the cutting bar in all trials that used the standard New Bedford dredge (3 of 3), in one-half of the trials that used the 2005 prototype (1 of 2), and in one-third of the trials with the 2006 prototype (4 of 12).

After the 2006 loggerhead carcass tests, the prototype was further modified by removing the “turtle guards” from the cutting bar and extending the outside bale bar 50 cm from the main frame before they tapered toward the gooseneck (hauling point) to increase the escape opening between bale and frame. The result of this series of modifications is called the Cfarm turtle excluder dredge (Figure 2). Because the final Cfarm turtle excluder dredge design differed slightly from the 2006 prototype, additional carcass tests were per-

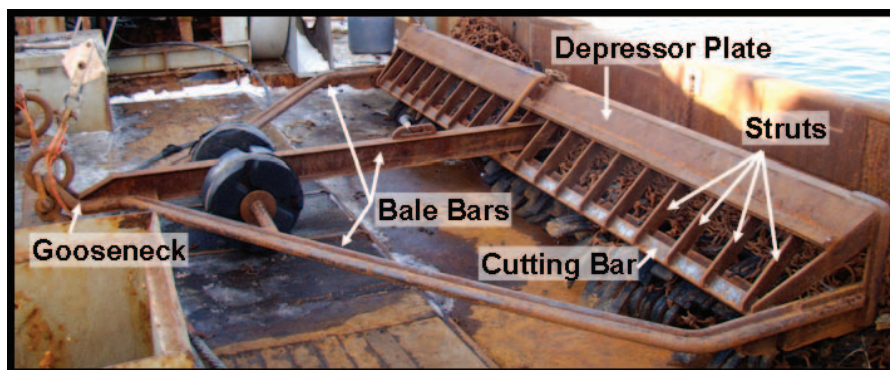


FIGURE 2.—Photograph of the Cfarm turtle excluder dredge.

formed to verify that (1) carcasses had minimal damage from impact with the dredge and (2) carcasses passed over the dredge frame rather than under the cutting bar.

Methods

The modified dredge was evaluated in Cape Cod Bay, Massachusetts, on September 9, 2008, using seven loggerhead carcasses and a commercial scallop vessel. The carcasses used were stranded sea turtles that the Virginia Aquarium Stranding response program (VAQS) necropsied then reassembled without their organs but with added weight in the body cavity so that the carcasses were slightly negatively buoyant in salt water. The carcasses were then frozen. Prior to use in this study, all carcasses were photographed, tagged, and inspected so that preexisting external damage was documented. The FV *Challenge*, a 20-m-long by 6-m-beam commercial scallop vessel, towed a 3.5-m-wide version of the turtle excluder dredge, outfitted with two bale wheels and a standard turtle chain mat. The dredge was towed at 6 km/h using 3:1 scope (30 m of towing wire in 10 m of water depth) consistent with industry practice. There were no Atlantic sea scallops in the tow area.

A three-member dive team operated from a separate vessel. Divers placed two surface buoys (approximately 15 m apart) in a line perpendicular to the tow path of the turtle excluder dredge. The surface buoys were set with minimal scope and anchored in 10-m-deep water with cement- and steel-filled buckets. Divers placed the carcasses (five for the first four passes and seven for the remaining passes) about 1 m apart in a line between the surface buoys. Visibility on the bottom was about 3–4 m at the beginning of the experiment, but decreased to only 1 m by the end, impairing divers' abilities to locate loggerhead carcasses and use hand-held cameras.

As the scallop vessel towed through the line of carcasses, four dredge-mounted video cameras docu-

mented the interactions between the modified dredge and the carcasses. Two camcorders (Panasonic SDR-H18 and Sony DCR-SR62) were placed into underwater housings and mounted on the bale, one on each side of the center bale bar. These cameras were aimed aft to view the cutting bar and frame. A third camera, an underwater Deep Sea Power & Light, Inc. (DSPL) model 2060 Multi-SeaCam mounted on the port end of the dredge depressor plate, was aimed across the dredge to gain a full view of the entire bale. This camera was connected by cable to an underwater housing containing a video recorder and power pack. The fourth camera, a similar DSPL model mounted just below the top of the dredge frame at the center, was aimed ahead to view most of the dredge bale. This camera, connected by cable to a monitor and recorder on the towing vessel, provided real-time images.

After all loggerhead carcasses were labeled and placed on the seafloor, the FV *Challenge* towed the modified dredge so that it passed between the two surface buoys. The real-time camera was monitored to determine whether any carcass interactions occurred. While we were able to observe an interaction, we were not able to determine which carcass was encountered as they were not retained by the gear. Carcasses that were encountered and went over the dredge, sometimes landed upside down and remained in that position until subsequently encountered on a later pass. For the purposes of this study, we do not believe a carcass with an upside-down orientation affected the results. After 11 passes between the surface buoys, divers attempted to locate all of the carcasses. Five of the seven carcasses were retrieved. Because the video recording did not show any carcasses being dragged along with the dredge, we think the two unrecovered carcasses were lost due to the decreased visibility at the end of the experiment. Hence, there is no reason to suspect the condition of the nonrecovered carcasses were different

TABLE 2.—Summary of interactions between carcasses and the Cfarm turtle excluder dredge. Carcass orientation is with respect to the oncoming dredge.

ID	Carcass orientation	Encounter description
1	Sideways and upside down	Turtle goes under starboard bale, flips over, and goes over the dredge frame, barely hitting the frame
2	Head first	Turtle goes under the end of the starboard bale, hits the cutting bar, and goes up and over the dredge frame
3	Head first, body at a 20° angle to dredge path	Turtle goes under the port bale, hits the cutting bar, and flips right over the dredge frame (Figure 3); the encounter lasts less than 2 s
4	Unobserved	Turtle caught in front of port bale wheel; turtle free from bale wheel, passes over bale and over frame
5	Unobserved	Turtle goes over starboard bale, hits frame, and goes right over dredge in less than 1 s
6	Sideways and upside down	Turtle hits cutting bar carapace first (turtle upside down) and goes right over dredge frame; bale encounter unobserved
7	Sideways	Turtle hits frame and goes right over; poor visibility; bale encounter unobserved
8	Unobserved	Turtle caught on starboard bale wheel, frees itself, and goes over dredge frame with minimal contact
9	Sideways	Turtle goes under port bale, carapace hitting cutting bar, and flips over frame in under 1 s

than that of the recovered carcasses. For example, if a carcass was dragged it may in fact show greater damage.

Results

Nine interactions between a loggerhead carcass and the modified dredge were documented on the video recordings (Table 2; Figure 3). Two carcasses went over the dredge bale, while seven went underneath the bale. Two of the carcasses that went under the bale hit

the hard rubber bale wheels and were hung up for a few seconds before passing the bale (one over and one under) and going over the dredge frame. In all nine interactions, the carcasses hit the dredge at some point and passed over the dredge frame. When all five carcasses were examined for injuries, the only observed carcass damage was superficial scratches and chips (Figure 4). None of the damage observed on the five recovered carcasses was consistent with a category I or category II injury (NMFS 2004).

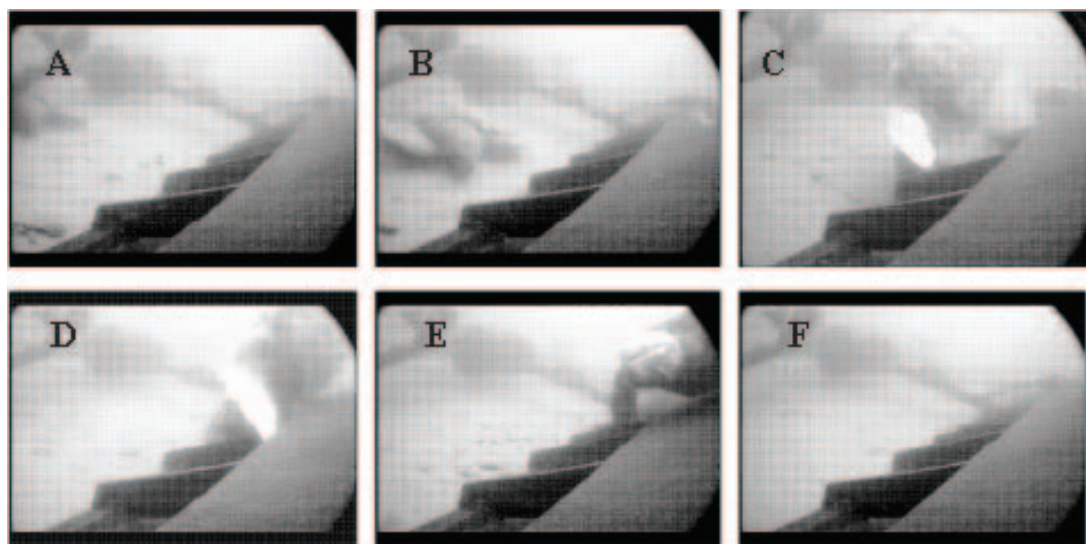


FIGURE 3.—Photographic sequence of a loggerhead sea turtle carcass encountering the Cfarm turtle excluder dredge: (A)–(B) the carcass first passes under the bale, then contacts the forward cutting bar, (C) gets deflected by the closely spaced struts, (D)–(E) is guided over the dredge frame, and (F) passes out of the view of the dredge-mounted video camera.

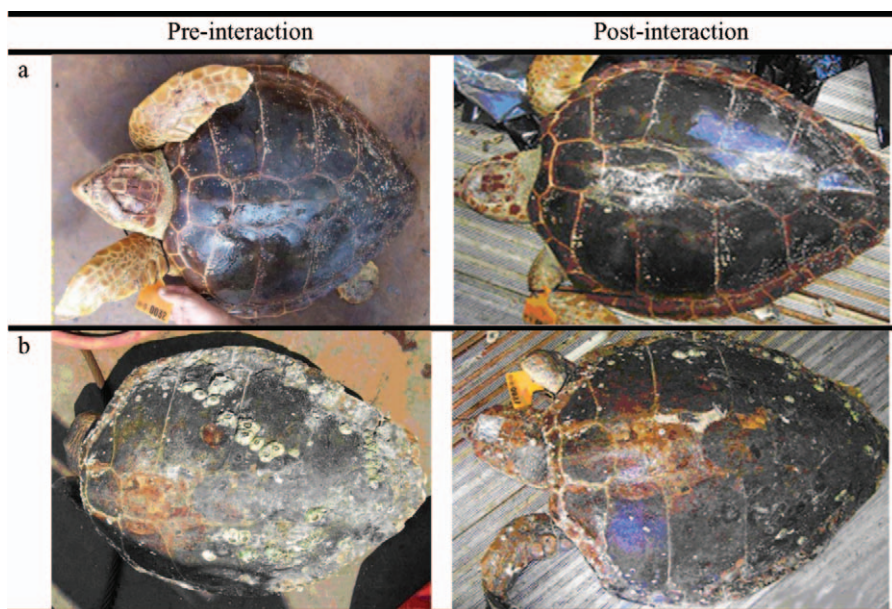


FIGURE 4.—Postinteraction carcass damage: (a) most loggerhead carcasses showed little or no damage after interacting with the turtle excluder dredge; (b) the most severe damage involved chips in the carapace scutes. Note that in both cases the damage to the head occurred during necropsy.

Discussion

Loggerhead carcass studies suggest the Cfarm turtle excluder dredge has the potential to minimize sea turtle injuries associated with interactions between sea turtles and scallop dredges fishing on the seafloor. In contrast to the standard New Bedford Atlantic sea scallop dredge, the Cfarm turtle excluder dredge deflected carcasses up and over the aft portions of the dredge frame rather than under the cutting bar. The magnitude and pattern of carcass damage observed during the experimental trials suggests that the most prominent benthic injuries occur when a turtle passes under the cutting bar. Carcass damage associated with serious (category I or II) injury was not observed when carcasses were hit by the dredge and guided over the dredge. None of the carcasses that passed over the aft portion of the dredge frame showed damage consistent with serious injuries.

This approach to mitigating sea turtle bycatch utilizes physical changes to the fishing gear rather than operational changes. The key elements of the modified design are the forward cutting bar (which results in a sloping rather than vertical face), the reduced number of bale support bars (just the center and outer bales), the extension of the outer bale bars before they taper to the hauling point, and the reduction of sources of entrapment between the depressor plate and cutting bar via the reduced spacing of struts.

Although several modifications were incorporated in the Cfarm turtle excluder dredge design, the fundamental design change was moving the cutting bar forward so the mechanical design and hydrodynamic forces would lift larger objects over the cutting bar. The success of this design was observed experimentally with the loggerhead carcasses and also with two American lobsters *Homarus americanus* that were encountered opportunistically and lifted over the cutting bar rather than under the cutting bar. This approach of using contact with hard gear to deflect sea turtles away from harm is consistent with other NMFS-accepted bycatch reduction devices for sea turtles (such as turtle excluder devices in shrimp trawl fisheries).

This gear-based approach has the potential to mitigate sea turtle bycatch without increasing bottom time (and consequent effects on other managed species and habitats) or economic impacts to the industry. In the commercial scallop fishery, the Cfarm turtle excluder dredge catches more Atlantic scallops and less fish bycatch (Smolowitz and Weeks 2008) than the standard New Bedford dredge. Broad time–area closures, in contrast, could result in spatial–temporal shifts in an effort that could adversely affect the bycatch of other NMFS-regulated species (such as yellowtail *Limanda ferruginea* and summer flounder *Paralichthys dentatus*) and may result in larger loss of revenue for the fishers. At least 42 Cfarm turtle

excluder dredges have already been built and are being used in commercial fisheries. These dredges appear to be fishing effectively in the flat sandy mid-Atlantic region where the majority of turtle interactions occur (Murray 2004a, 2004b, 2005, 2007), but they may not be strong enough to operate in the rocky areas of southern New England. Future improvements could include strengthening the dredge for use in hard-bottom areas or creating an even lower profile by further reducing the angle created between the seafloor, the cutting bar, and the depressor plate.

In order to minimize risks to live sea turtles, we used loggerhead carcasses as a proxy for live sea turtles. There are several important differences between these carcass studies and the interaction of live sea turtles with the actual fishery: (1) carcasses do not exhibit behavioral responses to the dredge; (2) carcasses may be structurally different from live sea turtles due to the necropsy procedure or decomposition; and (3) serious injuries cannot be fully evaluated by assessing external carcass damage (or external damage to live sea turtles). We do not have evidence to suggest that live turtle interactions with the turtle excluder dredge would be more severe than indicated by the damage observed to the carcasses. Using carcasses may represent the worst-case scenario because live sea turtles could exhibit escape behavior and may be structurally stronger than a decomposing carcass.

It is possible to test this dredge design in the commercial fishery with live sea turtles, but it would be costly. The number of hauls needed to detect a statistically significant difference (if one exists) between the standard New Bedford dredge and the Cfarm turtle excluder dredge depends on how effective the modification is at reducing the number of observed sea turtle catches. If (1) the sea turtle bycatch rate in the commercial study was the same as in a previous study documenting the effectiveness of the chain mat gear modifications (DuPaul et al. 2004), (2) the hauls were independent, and (3) the turtle excluder dredge reduced the observed turtle bycatch by 25%, then a power analysis indicates that over 5,000 hauls would be needed to detect a significant difference between the dredges (over 250 research days at sea).

Although the sea turtle conservation benefit of using the Cfarm turtle excluder dredge cannot be quantified at this time, there are documented advantages of using this dredge. Even if the turtle excluder dredge was 100% successful at eliminating benthic injuries to sea turtles, we still would not know the extent of reduction in total injuries because it is not known what percentage of turtle–dredge interactions are either benthic or pelagic (Haas et al. 2008). Nevertheless, the Cfarm turtle excluder dredge very probably reduces

risks associated with benthic interactions between sea turtles and dredges. The turtle excluder dredges catch more Atlantic sea scallops and less bycatch than the standard New Bedford dredge. In summary, there are economic and conservation benefits to using the Cfarm turtle excluder dredge rather than the standard New Bedford dredge, and there is no indication of increased risk or cost.

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